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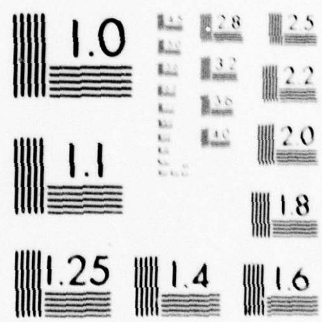

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MISCELLANEOUS PAPER HL-79-3

SPILLWAY VELOCITY MEASUREMENT AND FLIP BUCKET TRAJECTORY, RAYSTOWN DAM JUNIATA RIVER, PENNSYLVANIA

by

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March 1979

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314
and
U. S. Army Engineer District, Baltimore
Baltimore, Md. 21203

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper HL-79-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 SPILLWAY VELOCITY MEASUREMENT AND FLIP BUCKET TRAJECTORY, RAYSTOWN DAM, JUNIATA RIVER, PENNSYLVANIA.		5. TYPE OF REPORT & PERIOD COVERED Final report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Timothy L. Fagerburg		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314 and U. S. Army Engineer District, Baltimore P. O. Box 1715, Baltimore, Md. 21203	11	12. REPORT DATE March 1979 13. NUMBER OF PAGES 42
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 47p.		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) 14 WES-MP-HL-79-3 Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Chutes Flow characteristics Raystown Dam Spillways Velocity distribution Velocity measurement		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tests were conducted at Raystown Dam, Juniata River, Pennsylvania, to investigate flow characteristics of the left spillway and warmwater chutes. Velocity probes were installed in the chutes for measurement of the vertical velocity distribution. These measurements were used to study the boundary layer development and to determine an equivalent roughness for the spillway surface. Depths of flow along the spillway were measured with staff gages painted on the walls of the warmwater chute. The trajectories from the spillway flip bucket were photographed for each test and then (Continued)

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used to determine the height and length of the trajectory.

The equivalent sand grain roughness (K_s) determined for the Raystown spillway (0.00152 ft) supplements previous data. A more accurate determination of the boundary layer location could have been obtained had the velocity probes encompassed the entire depth of flow at each location on the spillway. Trajectories of flow deflected by the spillway bucket agreed with the model studies.

PREFACE

The prototype tests described in this report were conducted during the period 28 March through 1 April 1977 by personnel of the Hydraulics Laboratory (HL), U. S. Army Engineer Waterways Experiment Station (WES), for the U. S. Army Engineer District, Baltimore, and Office, Chief of Engineers, U. S. Army.

Acknowledgement is made to the individuals of the Baltimore District who contributed substantially to the completion of these tests. Mr. T. L. Fagerburg, hydraulic engineer, Prototype Branch, HL, was Project Engineer. This report was prepared by Mr. Fagerburg under the supervision of Mr. E. D. Hart, Chief, Prototype Branch; Mr. E. B. Pickett, Chief, Hydraulic Analysis Division; and Mr. H. B. Simmons, Chief, HL, all of WES.

COL J. L. Cannon, CE, was Commander and Director of WES during the course of the study and the preparation of this report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
gallon (U. S. liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
pounds (force) per square foot	47.88026	pascals

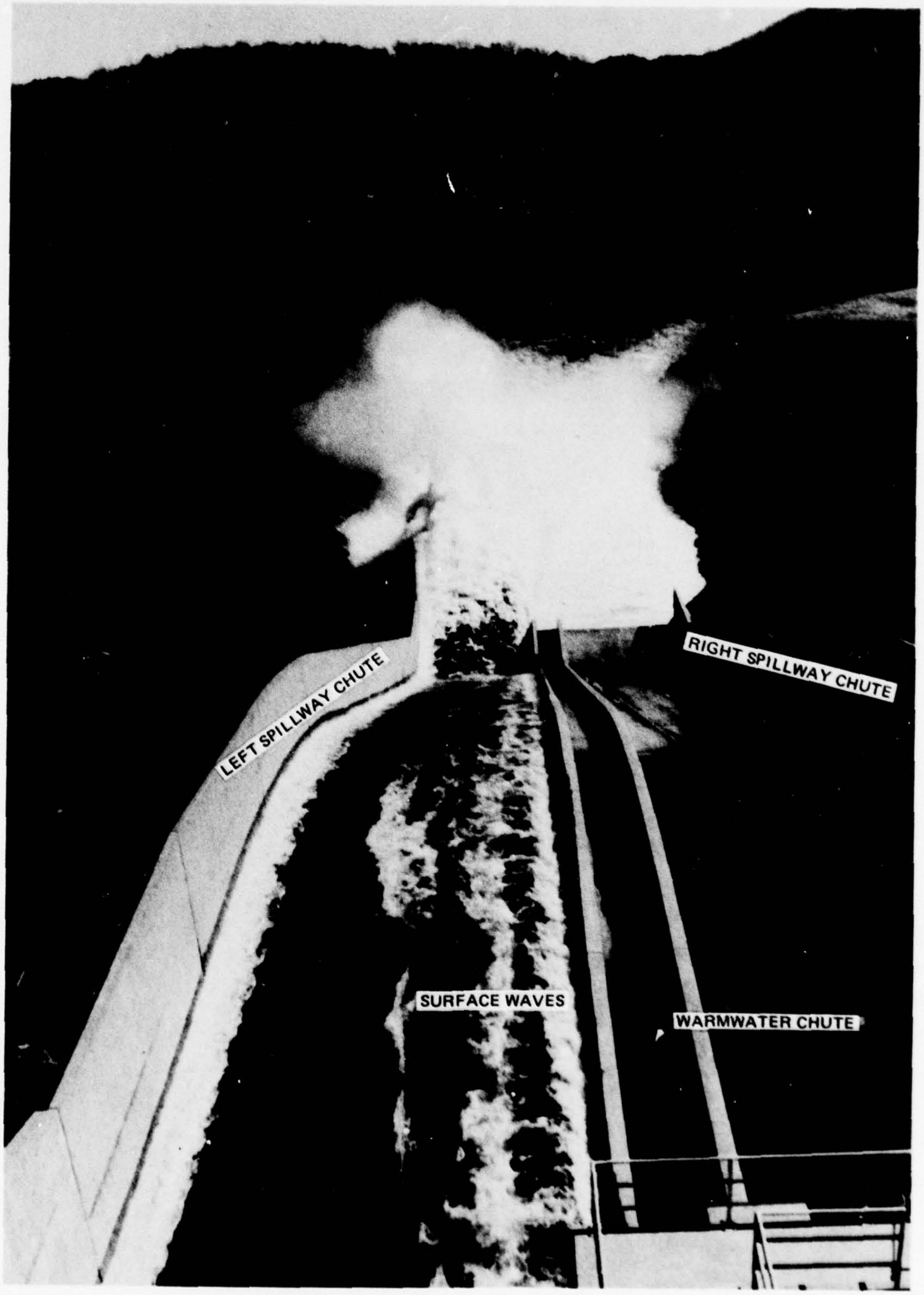

Figure 1. Operation of Raystown Dam for prototype testing

SPILLWAY VELOCITY MEASUREMENT AND FLIP BUCKET TRAJECTORY

Raystown Dam, Juniata River, Pennsylvania

PART I: INTRODUCTION

Pertinent Features of the Project

1. Raystown Dam (Figure 1) is a major element in the Susquehanna River Basin flood control system. Project purposes include providing flood control and downstream flow augmentation, as well as related benefits such as public recreation and enhanced fishery.

2. The structure is on the Raystown Branch of the Juniata River approximately 12.0 miles* south of the city of Huntington, Pennsylvania (Figure 2). The project layout is shown in Plate 1. The reservoir extends almost 27 miles upstream of the dam.

Description of the Structure

3. The dam is a rock- and earth-fill structure 1700 ft long that extends 225 ft above the streambed. The spillway consists of two 45-ft-wide chutes separated by a smaller 8-ft-wide by 7-ft-high rectangular warmwater chute. The spillways are controlled by 45-ft-high by 45-ft-wide conventional tainter gates and have a crest elevation of 768.6** Flows in warmwater chute are controlled by a 4-ft 9-in. by 6-ft 9-in. vertical slide gate. The intakes for the warmwater chute are located in the upper pool at el 766.0 and 750.0. The water is drawn from these different elevations for the purpose of controlling the water temperature in the downstream channel. The high walls surrounding the warmwater chute and the spillway contain the flow and allow the flip bucket to throw the flow away from the base of the spillway.

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* A table for converting U. S. customary units of measurement to metric (SI) units is given on page 3.

** All elevations (el) are in feet referred to mean sea level (msl).

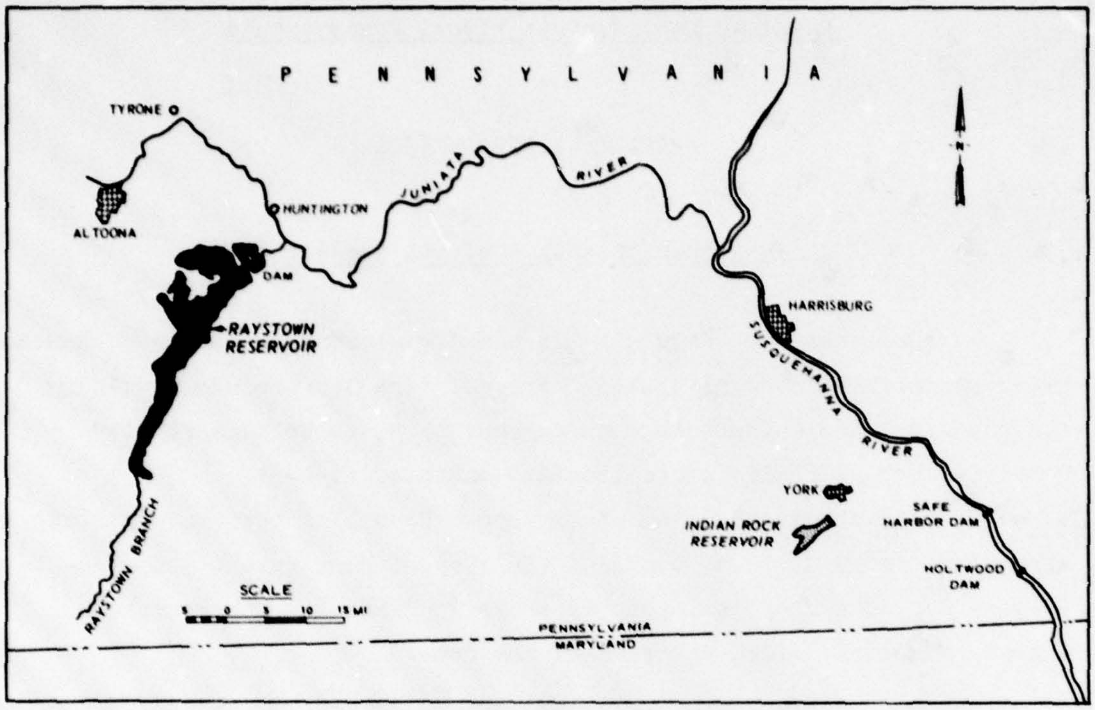

Figure 2. Vicinity map

Purpose and Scope of Tests

Purpose

4. At the request of the U. S. Army Engineer District, Baltimore, the U. S. Army Engineer Waterways Experiment Station (WES) conducted a series of spillway operation tests at Raystown Dam. Specific objectives of these tests were as follows:

- a. Study boundary layer development on the spillway and warmwater chutes.
- b. Determine the equivalent sand grain roughness of the spillway surface.
- c. Determine the water surface profiles on the spillway for various discharges.
- d. Derive the flip bucket characteristics from the field data.

5. Very little information is available on the full-scale performance of controlled spillways. The information gathered at Raystown is

for use in developing design criteria for future projects of the Corps of Engineers.

Scope

6. From 28 March to 1 April 1977, eight tests were conducted in two parts. The first set of tests (1-4) was conducted on flows in the warmwater chute and consisted of the following measurements:

- a. Pressure differential measurements between atmospheric pressure and the ten total head tubes on each of the four velocity probe assemblies in the chute (Plate 2). (Details of the velocity probe are presented in paragraph 9.)
- b. Photographs and measurements of water surface elevations at four locations down the warmwater chute (Plate 3).
- c. Determination of the characteristics of the flip bucket trajectory from photographs taken during the tests.
- d. Measurements of (1) pool elevation, (2) tailwater elevation, (3) gate opening, and (4) discharge.

7. The second set of tests (5-8) was conducted in the left spillway chute (looking downstream) and consisted of the following:

- a. Measurement of pressure differentials between a reference pressure and the ten total head tubes on each of the five velocity probe assemblies in the left spillway (Plate 2).
- b. Photographs and measurements of water surface elevations at 10 locations down the spillway (Plate 3).
- c. Determination of the characteristics of the flip bucket trajectory from photographs taken during the tests.
- d. Measurements as described in paragraph 6d.

PART II: TEST FACILITIES AND EQUIPMENT

Mounting Boxes

8. During construction of the dam, 13 mounting boxes for velocity probes were installed in the spillway floor (Plate 2). Boxes 1, 2, 3, 4, and 13 were designated for pressure measurements in the left spillway chute; boxes 5, 6, 7, and 8 were used in the warmwater chute. Boxes 9 through 12 were used only for access to the warmwater chute velocity probe tubing. Conduits connecting the spillway mounting boxes were used to pass the tubes from the velocity probes to the recording area located in the manometer well adjacent to the left training wall.

Velocity Probes

9. The velocity probe assemblies, designed and fabricated at WES, were used to measure pressure at 10 points ranging from 1/2 to 11-1/4 in. vertically above the spillway face. Figure 3 presents a velocity probe before and after assembly. Stagnation pressures are transmitted by the eight short tubes through the plastic lines to a recording location. Each of the two long (pitot) tubes on each probe encases a dual line for stagnation and static pressures. The velocity head was obtained from the difference between the stagnation and static pressures.

10. The gates to both the spillway and the warmwater chutes were closed to allow access of men and equipment. The cover plates were removed from all of the mounting boxes and pull wires were installed for pulling the plastic hydraulic lines through the embedded conduits (Figure 4). The instruments were installed first in the warmwater chute (Figure 5), and the leads from each probe terminated in the nearby boxes (9-12, Plate 2) in the left spillway chute (left refers to left side of the spillway when viewed in a downstream direction).

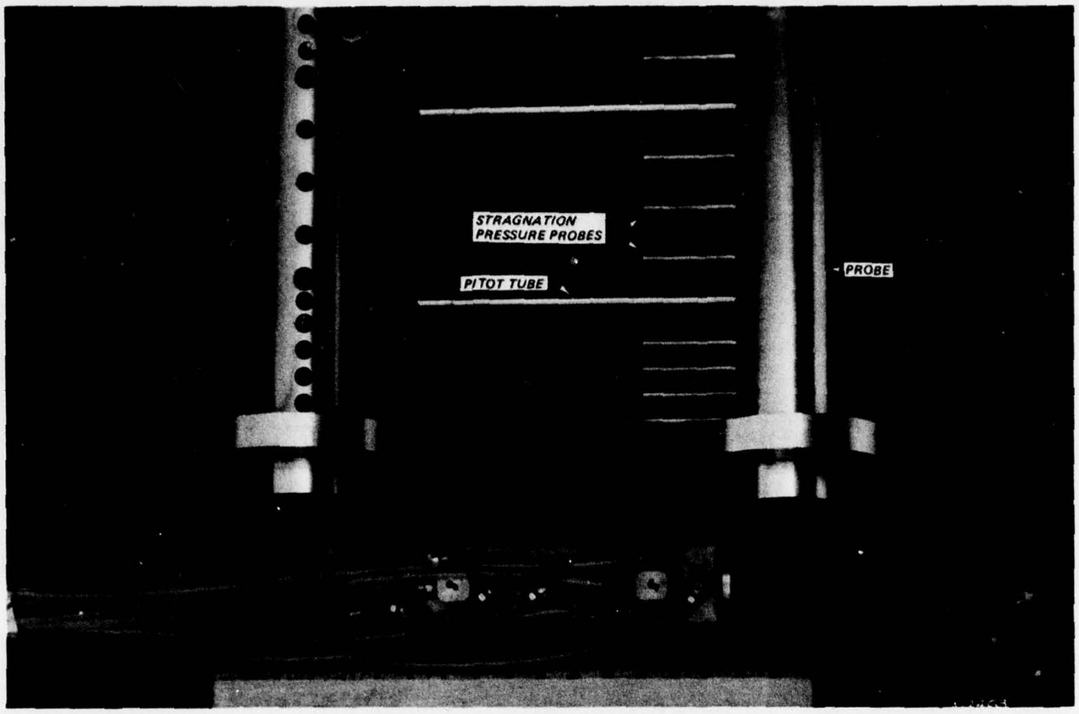

Figure 3. Spillway velocity probes (one assembled and one disassembled)

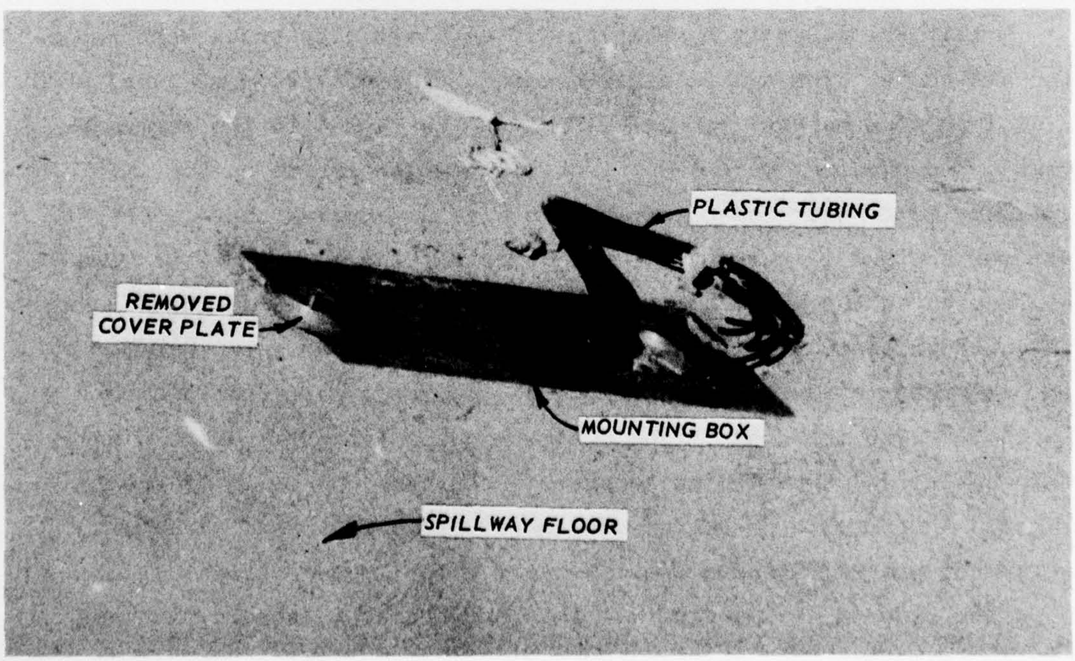

Figure 4. Plastic tubing extending from the embedded conduit

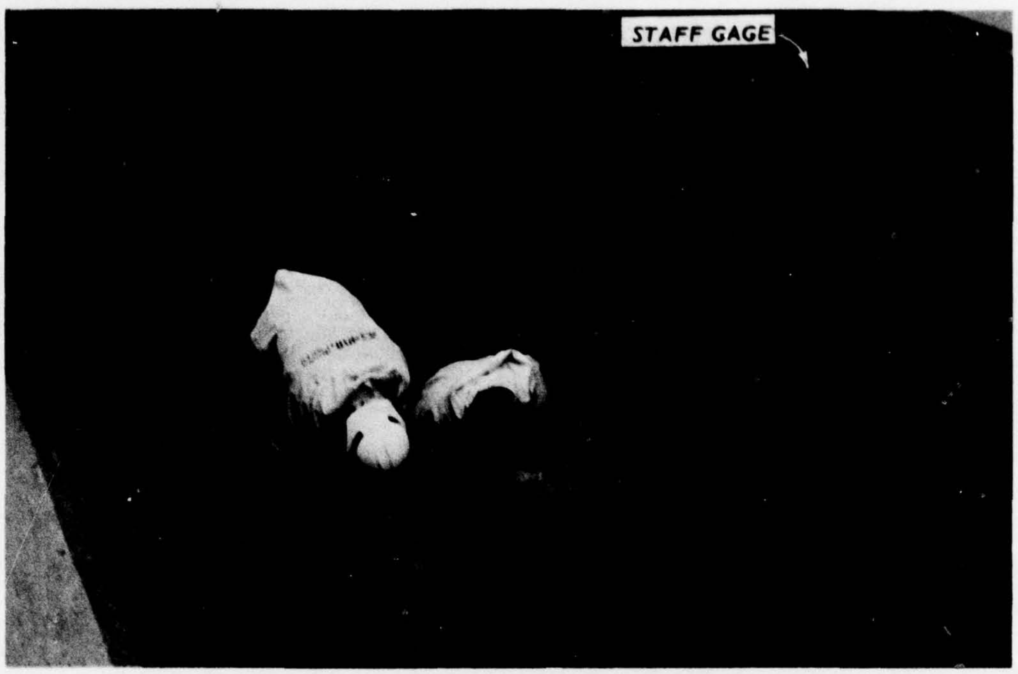

Figure 5. Installation of instruments in the warmwater chute

Pressure Measurements

11. Pressures from each line of each velocity probe were recorded for all tests. The static and stagnation pressures were measured with a differential mercury manometer. During tests 1-4 in the warmwater chute, the readings were taken from a manometer set up in the left spillway chute near the corresponding access mounting box. A special manometer stand (Figure 6) was used that allowed the manometer base to be leveled on the steep slope. The pressures measured during the warm-water chute tests were referenced to atmospheric pressure (one leg of the manometer open to the atmosphere). The pressures recorded for tests 5-8 were measured in the manometer well (Plate 2) where a manifold system was arranged to separate the probes and their hydraulic lines. A reference pressure, created by filling a 55-gal drum with water and placing it at a specified elevation, was applied to the opposite side of the manometer. This reference pressure, which was always less than the pool pressure, was moved to various selected elevations, when necessary, to prevent over-ranging the manometer.

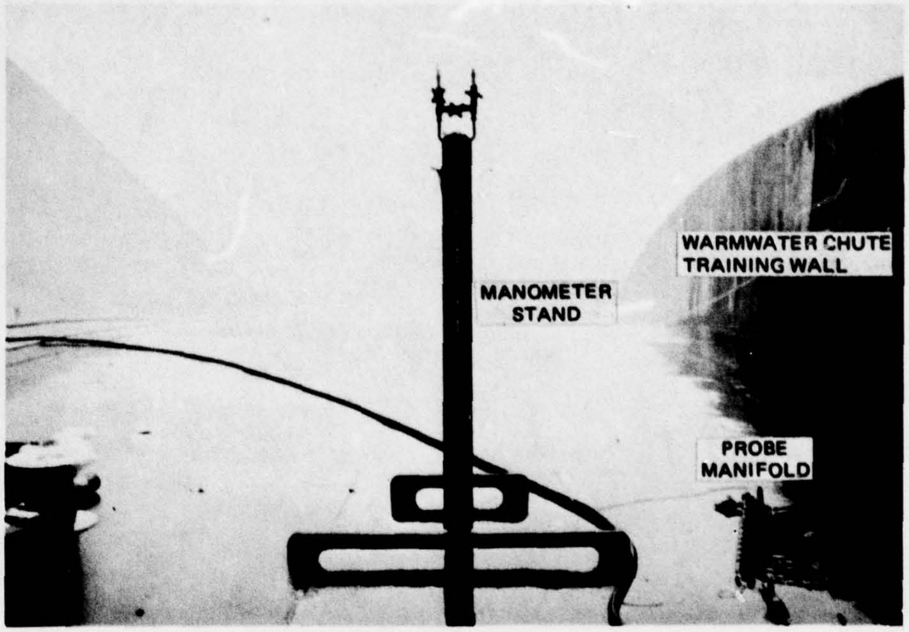

Figure 6. Downstream view of adjustable manometer stand

Other Measurements

12. Water surface elevations were measured in both test chutes for all appropriate tests. Staff gages (Figure 7) were painted on the inside wall of each test chute. Plate 3 shows the locations of the staff gages for both chutes. Photographs were taken of the flip bucket trajectory (Figure 8) for all tests. These photographs were used to determine the height and length of the trajectory for various discharges and tailwater elevations. The U. S. Geological Survey obtained the discharge measurements during the tests, utilizing the velocity-area method of discharge determination. The location for the measurements was approximately one-half mile downstream of the dam at a permanent stream gaging station.

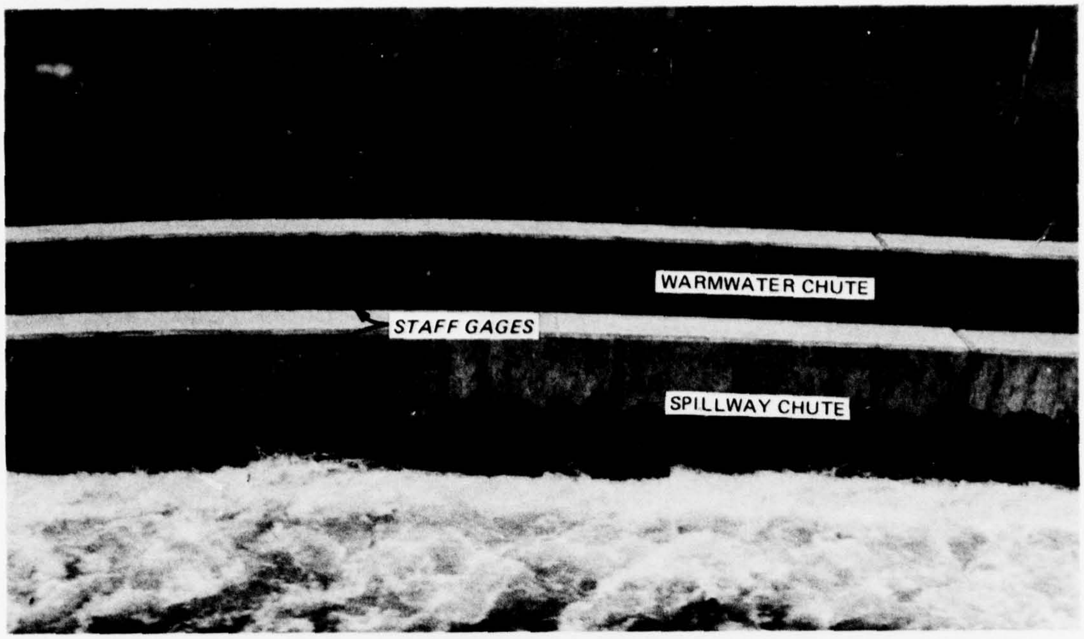

Figure 7. Typical staff gages for water surface elevation measurements

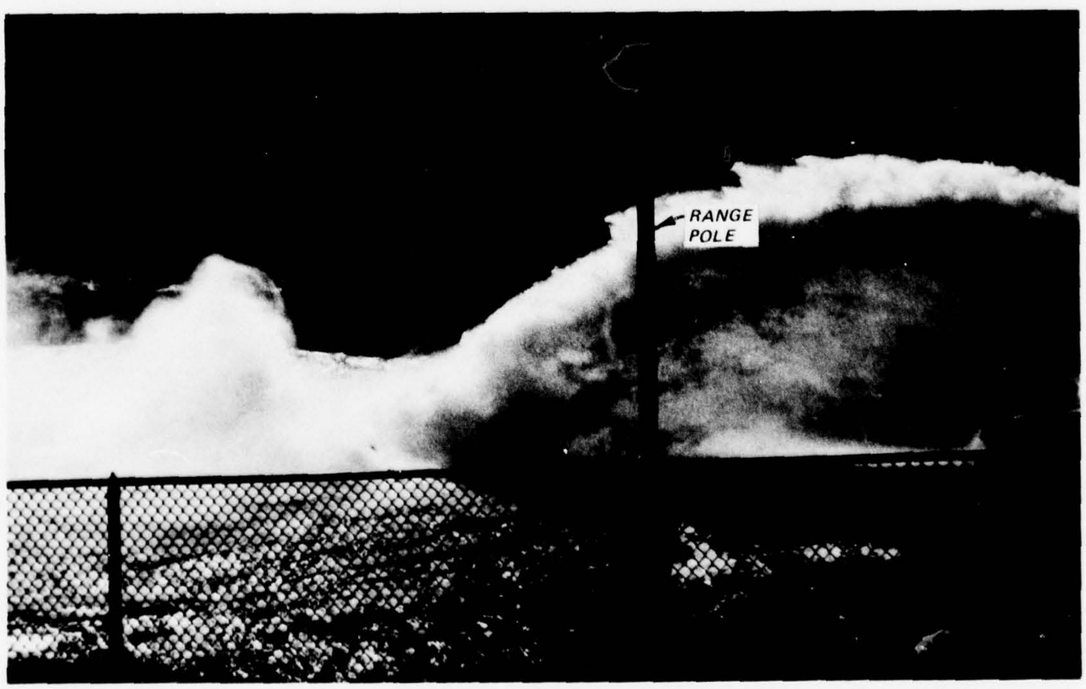

Figure 8. Photograph of the flip bucket trajectory. (Note the range pole in foreground.)

PART III: TEST CONDITIONS AND PROCEDURES

Test Conditions

13. As mentioned previously, eight tests were conducted in two parts at Raystown Dam. In the first four tests (warmwater chute), measurements were made of pressure profiles (for determining velocity profiles), water surface elevations, and discharge. Tests 5-8 were conducted in the left spillway chute and the same types of measurements were made. The following tabulation lists the test conditions:

Test No.	Gate Opening ft	Discharge cfs	Pool Elevation ft msl	Tailwater Elevation ft msl	1977 Date	Time
			Warmwater Chute			
1	7.0*	1460	787.00	602.87	3-28	1650
2	3.8	731	787.22	601.83	3-29	0900
3	2.6	446	787.70	601.35	3-29	1430
4	1.0	183	787.88	600.66	3-30	0930
			Left Spillway Chute			
5	2.1	1996	788.00	603.50	3-30	1400
6	5.4	4970	788.12	606.08	3-31	1250
7	8.8	7842	788.02	607.98	3-31	1630
8	15.0	12,178**	787.00	610.54	4-1	0900

* Full open.
** Uncontrolled flow.

Test Procedures

14. Procedures for tests 1-4 were as follows:

a. Close gates to warmwater chute; remove cover plates and install velocity probes.

b. Open the warmwater slide gate to obtain desired discharge.

c. Purge air from all lines.

d. Open each line of each velocity probe assembly (separately) and record the differential of the mercury manometer.

e. Record the elevation of the manometer on the spillway.

f. Photograph and record the water surface elevation in the warmwater chute at the staff gages.

g. Photograph the flip bucket trajectory.

h. Record the upper and lower pool elevations, gate opening height, and discharge rate.

15. Procedures for tests 5-8 were the following:

a. Close gates to the warmwater chute, remove velocity probes, and install them in left spillway chute.

b. Open the tainter gate to the desired position.

c. Purge air.

d. Open each line of each velocity probe assembly (separately) and record the differential of the mercury manometer.

e. Record the elevation of the water surface in the reference pressure barrel.

f. Photograph and record the water surface elevation in the spillway chute at the staff gages.

g. Photograph the flip bucket trajectory.

h. Record the upper and lower pool elevations, gate opening height, and discharge rate.

PART IV: TEST RESULTS AND ANALYSIS

Velocity Profiles

Velocity calculations

16. The velocity for each stagnation pressure tube was calculated from the total head measurements obtained from the manometer readings. Static pressures from the side ports of the two pitot tubes were inadequate to purge the piezometer lines; therefore, these pressures were not recorded. A hydrostatic pressure distribution was assumed. The resulting velocity values are shown in Tables 1 and 2.

Velocity distribution

17. The velocity profiles at various test discharges Q* at the probes for both sets of tests are presented in Plates 4 and 5. The velocity distributions are well represented by a logarithmic equation. The best fitting logarithmic curves for the data were determined by the method of least squares. The curves are of the form

$$U = a \log_{10} y + b \tag{1}$$

where

U = local velocity

y = vertical distance above the chute floor, ft

a,b = dimensional constants

18. The equivalent sand grain roughness K_s and the variation of boundary shear stress τ_o along the spillway surface are of considerable interest. However, in order to estimate K_s and τ_o for the test data, some analogy must be inferred between the flow over the spillway crest and the flow in a more thoroughly researched situation. Three such analogies and the resulting values are described in the following paragraphs.

---

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

19. Rough-pipe velocity distribution. The rough-pipe velocity distribution law[1,2] states that

$$\frac{U}{U^*} = A \log_{10} \frac{y}{K_s} + B \quad (2)$$

where

A,B = dimensionless constants

U = local velocity, ft/sec

U^* = shear velocity, ft/sec = $\sqrt{\frac{\tau_o}{\rho}}$ where τ_o is the boundary shear stress, lb/ft^2 and ρ is the fluid density, slugs/ft^3

y = distance from the wall, ft

K_s = equivalent sand grain roughness, ft

For Equation 1 to be identical to Equation 2

$$a = A\ U^* \quad (3)$$

and

$$b = U^*(B - A \log_{10} K_s) \quad (4)$$

When the rough-pipe values of A and B, 5.75 and 8.5 respectively, are assumed to apply to the spillway, then U^* may be evaluated from Equation 3 and K_s from Equation 4. These values are listed below for test 8 (free-surface, ungated flow).

Parameter	Rough-Pipe Values Probe 1	Probe 2	Probe 3	Probe 4
a	12.63	16.71	17.12	17.22
b	56.65	62.06	69.60	80.17
U^*, fps	2.20	2.91	2.98	2.99
K_s, ft	0.00100	0.00588	0.00261	0.00065

20. Moody diagram (established flow analogy). The K_s for each probe was also computed by finding the resistance coefficient, determined from the energy loss between each probe, and using a Moody diagram to obtain a relative sand grain roughness value K_s/D. The following values of K_s were obtained.

Test No.	K_s, ft			
	Probe 1	Probe 2	Probe 3	Probe 4
5	0.00032	0.00365	0.00363	0.00410*
6	0.00032	0.00920	0.00780	0.00924*
7	0.00022	0.00106	0.00061	0.00046
8	*	0.00748	0.00340	0.00152

* These data believed inaccurate, due to air in velocity probe lines.

The average K_s value obtained in this manner was 0.0062 ft.

21. According to Schlichting,[3] the equivalent roughness decreases with distance downstream due to the increasing thickness of the boundary layer. Therefore, the K_s value that would most likely represent the surface of the spillway would be the value that is obtained where the fully developed velocity profile occurs. The equivalent roughness value (K_s = 0.00152 ft) obtained from data measured at the furtherest point downstream of the leading edge of the spillway during test 8 is the value that is most representative of the spillway surface.

22. Rough flat-plate analogy. The local skin friction coefficient c_f' is defined as

$$c_f' = \frac{\tau_o}{1/2\rho\ U_\infty^2} \tag{5}$$

where U_∞ is free stream velocity. For fully rough flow along a flat plate, c_f' is evaluated from

$$c_f' = \left(2.87 + 1.58 \log \frac{x}{K_s}\right)^{-2.5} \tag{6}$$

where x is the distance downstream from the leading edge of the plate. Combining Equations 5 and 6

$$U^* = \left\{1/2\left[\left(2.87 + 1.58 \log \frac{x}{K_s}\right)^{-2.5}\right]U_\infty^2\right\}^{1/2} \tag{7}$$

When U_∞ is assumed to equal the velocity of the water surface* and K_s is assumed to be a constant (0.00152 ft as described in paragraph 21), then the following test 8 values of U^* are obtained from Equation 7.

Parameter	Rough Flat-Plate Values: Probe 1	Probe 2	Probe 3	Probe 4
x, ft	182	269	358	450
Z, ft-datum	745	722	680	643
U_∞, fps	52 (55)	65 (65)	83 (70)	96 (80)
U^*, fps	1.86	2.26	2.80	3.20

Note: The values in parentheses are directly from velocity probe data; note that at probes 3 and 4 either the energy loss or the flow curvature cause the ideal-flow values to deviate substantially from the measured values. Since the calculated values of U^* are relatively insensitive to the value of K_s, Equation 7 appears to be a reasonable means of estimating boundary shear until the ideal-flow value of U_∞ becomes valid.

Boundary Layer Thickness

23. The theoretical boundary layer thickness δ was computed according to the following equation for a rough bed:[4]

$$\delta = 0.0447 K_s^{0.154} x^{0.846} \tag{8}$$

The following tabulation lists the computed boundary layer thicknesses at the probe locations according to the two values of K_s.

K_s = 0.0062 ft: Probe 1	Probe 2	Probe 3	Probe 4	K_s = 0.00152 ft: Probe 1	Probe 2	Probe 3	Probe 4
1.67	2.32	2.96	3.58	1.35	1.87	2.39	2.89

Figure 9 shows a plot of the boundary layer thickness and the measured depth of flow d versus the length of the spillway channel. Hydraulic

* $U_\infty = \sqrt{2g(H-Z)}$ for no energy loss at the surface where g is acceleration due to gravity, H is elevation of upstream water surface, and Z is elevation of the local water surface.

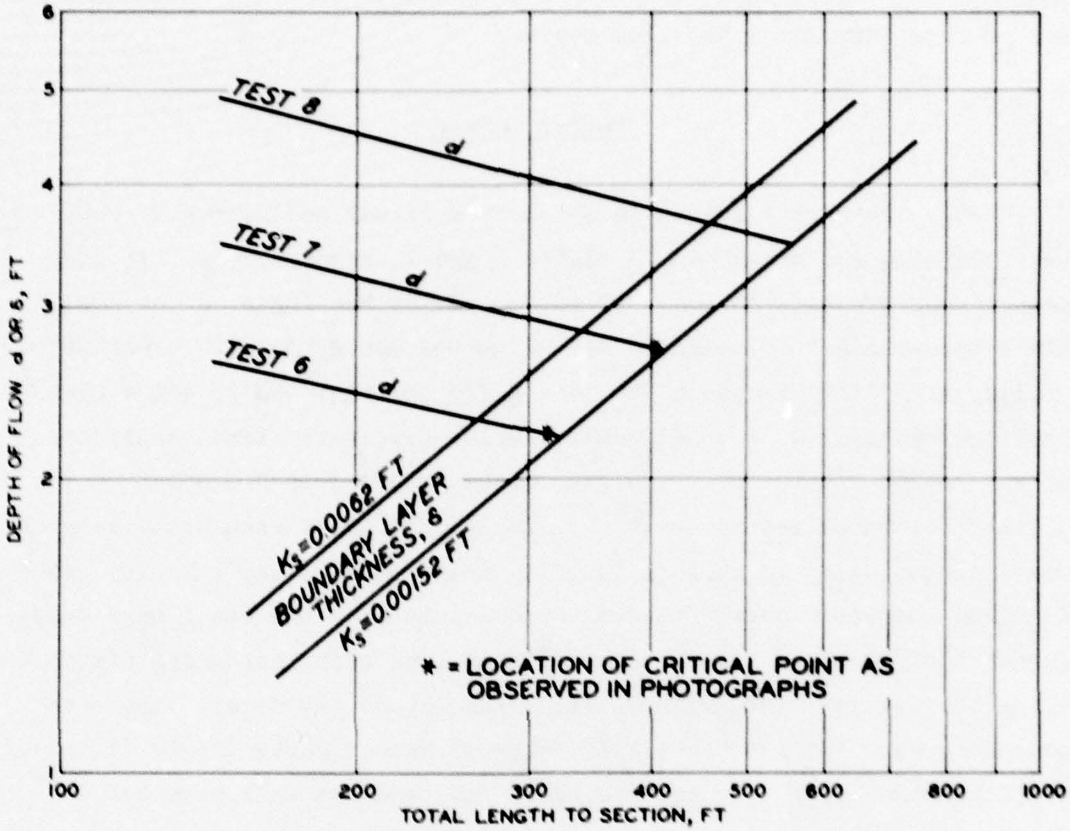

Figure 9. Location of critical point

Design Criteria (HDC) Sheet 111[5] states that if the computed boundary layer thickness becomes larger as the depth of flow decreases, then the critical point, the intersection of the water surface and the boundary layer, can be located.

24. It has been observed from various prototypes that the first occurrence of the "foaming line" or "white water" is that point (defined "critical point") where the turbulent layer reaches the water surface.[6] Photographs were taken during each of the spillway tests at various locations to determine the positions of the critical point. Figure 9 shows the close agreement between the observed and the computed critical point for tests 6, 7, and 8. The observed critical point for test 8 did not appear to reach the surface until the point at which the flow exited the spillway chute. The critical point could not be observed in the

other tests because the flow conditions were such that the foaming line was present throughout the flow regime.

Energy Losses

25. The energy losses in the left spillway and warmwater chutes were computed and are shown in Plates 6 and 7, respectively. It has been common practice in the past to use either Manning's n or some other open-channel equation to determine the energy loss in overflow spillways.[7] Since Raystown Dam is a gated spillway and is not a high overflow spillway with a uniformly sloping downstream face, application of the method of obtaining energy losses discussed in HDC Sheet 111-18/5[5] was subject to question. The head loss at each spillway probe was computed using an average velocity obtained from the velocity probe data and the water depth measurement obtained from the staff gage readings. Plate 6 shows the accumulated head loss with increasing distance along the left spillway with 20 ft of head above the crest. The same procedure was used for tests 1-4 in the warmwater chute (Plate 7), except that the losses through the trash rack and wet well were not computed. The energy loss computations for these tests start at the vertical lift gate and proceed downstream. The design curves from HDC 111-18/3 for a high overflow spillway with a design head of 20 ft are presented in Plates 6 and 7 and show good agreement between the design curve and the measured data, even though the Raystown spillway profile is quite different from that of a high overflow spillway.

Water Surface Profiles

26. As stated previously, staff gages were painted at various locations along the inner wall of each test chute. The staff gages were oriented perpendicular to floor of the chutes to enable a direct visual reading of the water depth and to make photographs. It was from these photographs that the critical point discussed in paragraph 24 was determined. Table 3 lists the water depths and the corresponding staff

gage locations for all tests. Plates 8 and 9 show computed water surface profiles plotted along with the measured flow depths of representative tests for the spillway and warmwater chutes. The computed profiles were obtained from a WES computer program[8] for determination of flow profiles in a straight prismatic channel. In the program, Manning's resistance formula was used and the value of Manning's resistance coefficient and energy correction factor were 0.013 and 1.15, respectively. Some fluctuation can be seen in the plotted data; this is attributed to the difficulty in measuring a rough water surface due to waves created by the side walls and construction joints (see Figure 1).

Flip Bucket Trajectories

27. The length and height of the flip bucket trajectories for all tests were obtained from photographs. The camera and a range pole were positioned at known elevations and distances from the center line of the spillway as shown in Plate 10. Several frames were taken of each discharge once the flow was well developed. From these photographs the measurements of the throw distance and height of the trajectories were estimated by geometric ratios and are plotted in Plate 11. Photographs 1 and 2 present the associated scales for throw distance and height for tests conducted in the spillway (test 6) and warmwater chutes (test 1). For convenience, not all photographs are shown. The trajectories of some of the tests were compared with the maximum predicted trajectories from the Raystown Design Memorandum (DM)[9] and trajectories from Raystown model studies.[10] Plate 12 shows the comparison of the actual and predicted trajectories of selected flows. The actual throw distances were less than those predicted in the DM even in the case of a higher flow versus a lower flow. This difference may be partially due to wind resistance not considered in the computations. (See comparison of actual trajectories for Q = 12,178 cfs versus the DM predicted trajectory for Q = 10,000 cfs.) The comparison of the prototype and model trajectories shows good agreement at various discharges. The height of the trajectory was consistently higher than the predicted

height. This difference may be the result of inaccuracies in scaling the trajectories from the photographs. Some distortion of vertical and horizontal distances does occur in photographs that are taken from long range, and inaccuracies can result.

PART V: CONCLUSIONS

28. The following conclusions resulted from analysis of the test data.

a. The theoretical boundary layer thickness δ computed according to the following equation

$$\delta = 0.0447\ K_s^{0.154} x^{0.846} \tag{8}$$

is generally confirmed by the photographs and computation of the critical point.

b. The equivalent sand grain roughness $K_s = 0.00152$ ft determined for the Raystown Spillway agrees well with results of previous investigations.

c. The performance of the velocity probes was satisfactory. However, a more accurate determination of the boundary layer location could have been obtained had the probes been long enough to encompass the entire depth of flow.

d. The flip bucket trajectories obtained at Raystown agree well with those values obtained from the model investigation and design data. However, an accurate determination of trajectories is difficult.

e. The energy loss data presented in Plates 6 and 7 show significant agreement with the design curve from HDC 111-18/3, although the profile of Raystown Spillway chute is quite different from that of a typical high overflow spillway.

REFERENCES

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10. Oswalt, N. R., Murphy, T. E., "Gated Spillway for Raystown Reservoir, Juniata River, Pennsylvania," Technical Report H-70-15, Dec 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

Warmwater Chute Velocity Profiles, in Feet per Second

Distance from Spillway Floor, ft	Probe 5	Probe 6	Probe 7	Probe 8	Probe 5	Probe 6	Probe 7	Probe 8
	Test 1				**Test 2**			
0.94	42.91	*	*	62.80	47.27	*	53.88	40.45
0.81	41.95	48.10	57.43	63.20	46.53	53.94	53.79	39.18
0.69	28.37	47.20	52.25	61.14	34.42	52.79	48.15	33.90
0.56	*	43.72	53.25	60.53	*	52.29	48.07	29.48
0.44	*	43.69	57.43	59.25	38.99	49.61	48.57	24.33
0.33	34.09	42.88	56.38	57.29	41.18	49.04	*	*
0.23	33.56	39.47	59.69	*	38.0	45.18	50.57	70.48
0.17	31.40	38.10	58.50	*	36.88	43.98	50.08	74.94
0.10	31.20	36.03	54.46	55.33	34.73	40.90	48.92	54.51
0.04	27.75	30.56	49.44	49.52	31.28	36.41	47.90	48.93
	Test 3				**Test 4**			
0.94	46.51	*	57.83	57.47	*	*	*	*
0.81	46.41	48.87	58.12	61.78	*	*	*	*
0.69	*	48.77	*	58.07	36.83	33.34	*	*
0.56	*	47.31	*	55.77	36.16	42.50	47.61	48.68
0.44	*	45.22	*	47.64	34.16	42.04	45.73	40.77
0.33	40.34	43.85	48.71	51.52	33.49	41.32	47.24	45.56
0.23	38.80	41.80	46.58	53.20	31.04	38.12	42.96	43.19
0.17	36.70	39.65	44.06	44.60	29.24	35.97	40.87	37.45
0.10	34.69	36.90	41.19	40.70	26.68	33.76	38.04	34.22
0.04	30.50	32.89	37.39	36.17	24.49	29.79	34.25	31.67

* Piezometer line clogged.

Table 2

Left Spillway Chute Velocity Profiles, in Feet per Second

Distance from Spillway Floor, ft	Probe 1	Probe 2	Probe 3	Probe 4	Probe 13	Probe 1	Probe 2	Probe 3	Probe 4	Probe 13
	Test 5					Test 6				
0.94	*	70.12	*	67.70	71.71	52.30	70.05	82.12	85.86	90.04
0.81	*	70.74	68.62	70.88	73.71	53.15	70.15	80.12	*	90.49
0.69	60.98	70.03	70.71	72.88	74.69	50.12	69.95	78.60	84.51	89.59
0.56	65.24	67.27	69.14	71.99	75.12	47.23	67.63	77.72	82.86	89.50
0.44	60.07	64.52	67.19	69.03	74.04	45.48	64.0	76.46	80.39	87.95
0.33	62.86	66.26	59.75	69.94	75.83	44.77	66.60	*	78.14	89.14
0.23	61.09	61.25	64.87	68.06	75.23	42.16	63.69	70.34	75.72	88.74
0.17	59.88	59.46	58.66	66.01	73.09	41.03	62.85	67.28	72.89	84.19
0.10	58.55	56.21	57.54	64.52	71.59	37.74	59.0	65.08	69.71	80.96
0.04	56.29	55.02	59.96	63.13	69.53	33.57	56.19	60.97	65.77	76.86
	Test 7					Test 8				
0.94	*	57.67	73.16	90.63	85.07	*	63.36	70.03	78.97	80.48
0.81	51.17	57.17	72.02	89.03	85.82	52.98	61.60	69.56	79.20	82.86
0.69	50.85	56.77	70.22	86.05	86.20	54.31	59.46	67.20	78.87	80.89
0.56	49.40	54.62	69.06	85.25	86.57	54.33	57.69	64.74	77.54	81.28
0.44	48.30	52.32	66.68	82.59	83.53	52.95	54.40	63.22	72.58	79.68
0.33	45.47	51.19	57.68	79.60	84.97	50.61	53.44	*	71.12	78.45
0.23	42.30	48.26	70.58	76.28	86.95	47.30	50.44	56.64	68.71	81.68
0.17	41.18	45.65	67.17	73.47	82.75	46.62	48.08	55.04	65.33	76.78
0.10	38.45	42.56	64.34	71.23	79.56	43.30	45.02	51.74	62.81	73.33
0.04	35.48	38.57	60.98	65.06	71.87	39.88	40.48	47.90	57.42	68.30

* Piezometer line clogged.

Table 3

Staff Gage Locations and Flow Depths

Station	Warmwater Chute Water Depths, ft: Test 1 Gate Open 6.9 ft (Full)	Test 2 Gate Open 3.8 ft	Test 3 Gate Open 2.6 ft	Test 4 Gate Open 1.0 ft
13+00	4.80	3.00	1.75	1.00
13+85	4.85	2.20	1.50	0.75
14+75	3.85	2.25	1.50	0.80
15+57	2.00	2.20	1.60	0.85

Station	Left Spillway Chute Water Depths, ft: Test 5 Gate Open 2.1 ft	Test 6 Gate Open 5.4 ft	Test 7 Gate Open 8.8 ft	Test 8 Gate Open 15.0 ft
12+55	1.20	2.50	3.50	4.75
13+00	1.25	2.50	3.30	4.50
13+38	1.25	2.40	3.10	4.00
13+85	1.25	2.20	3.00	4.00
14+30	1.25	2.25	3.00	4.00
14+75	1.20	2.25	2.80	4.00
15+16	1.20	2.25	2.50	3.80
15+57	1.20	2.25	2.50	3.80
15+96	1.30	2.20	3.00	4.50
16+20	1.50	3.00	3.75	4.50

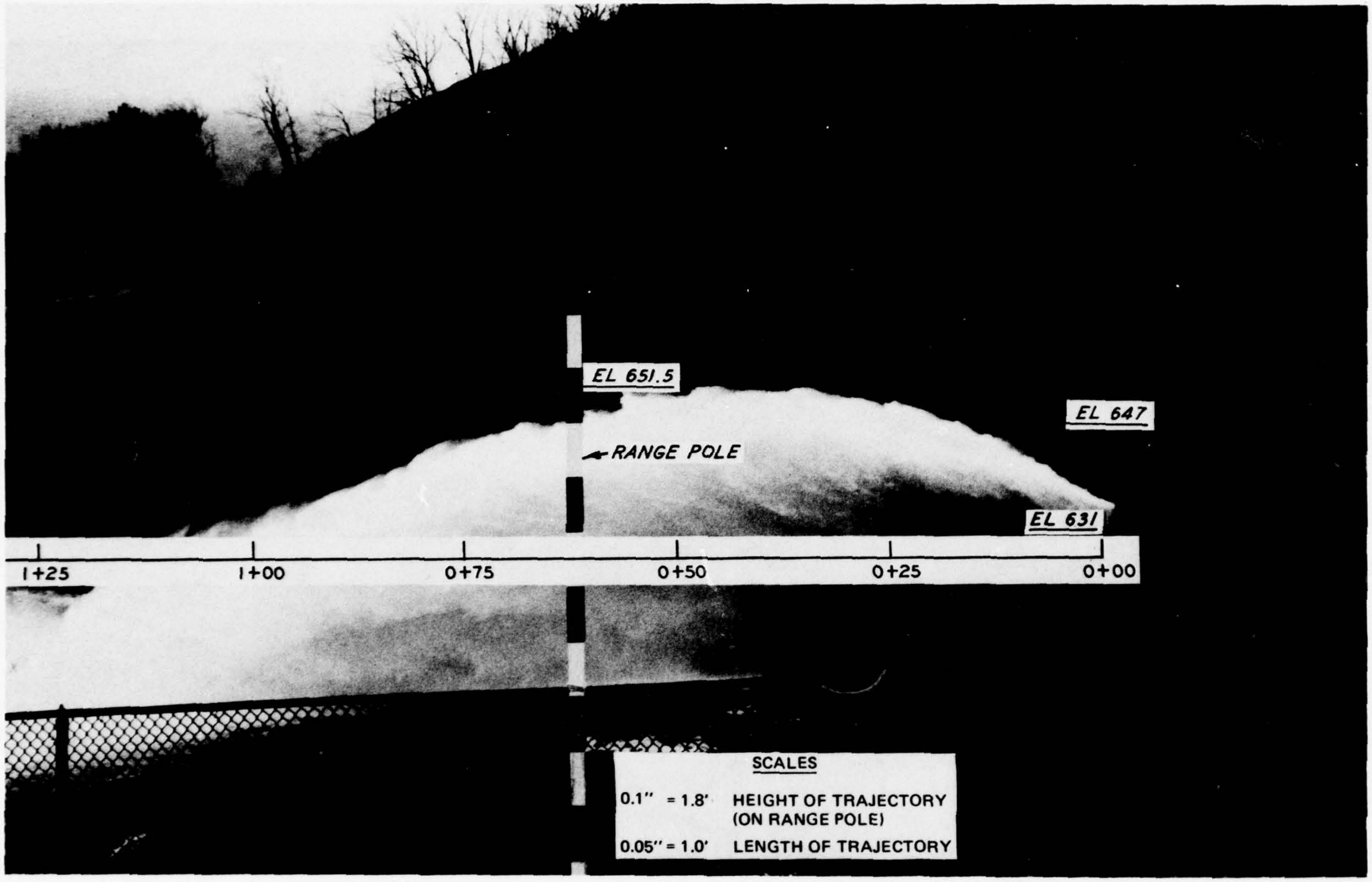


Photo 1. Determination of flip bucket trajectories and heights from actual photographs (Test 1)

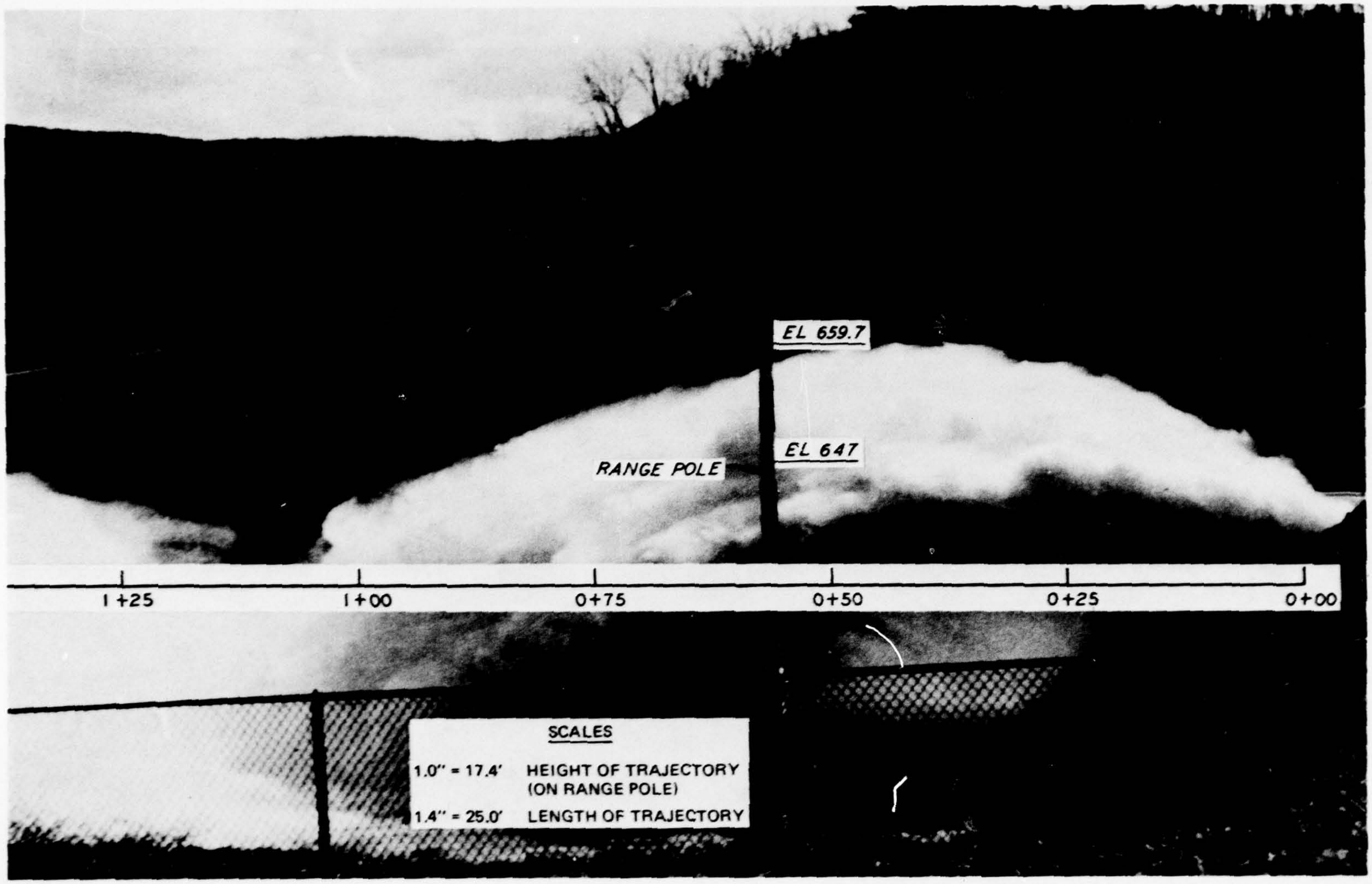


Photo 2. Determination of flip bucket trajectories and heights from actual photographs (Test 6)

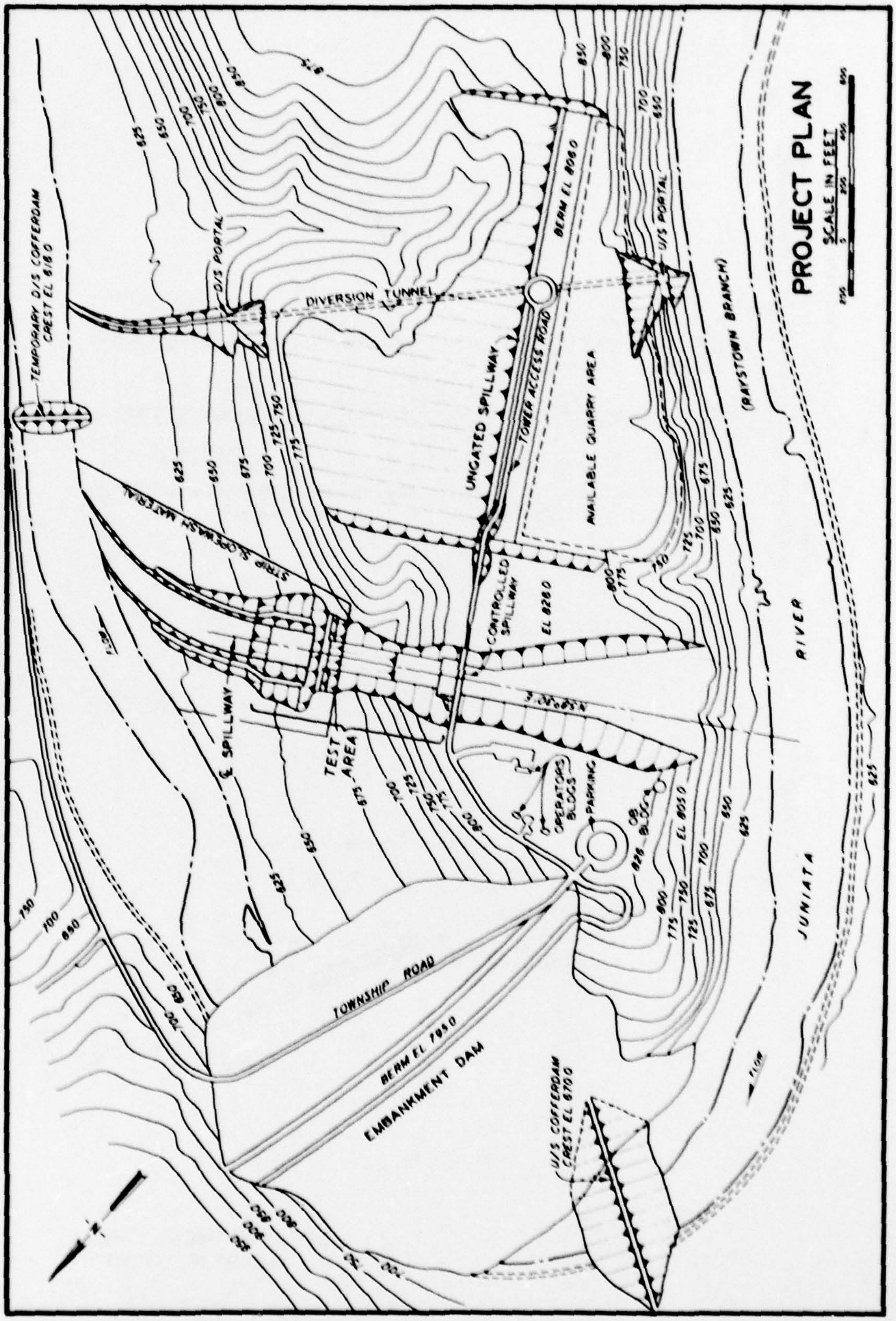
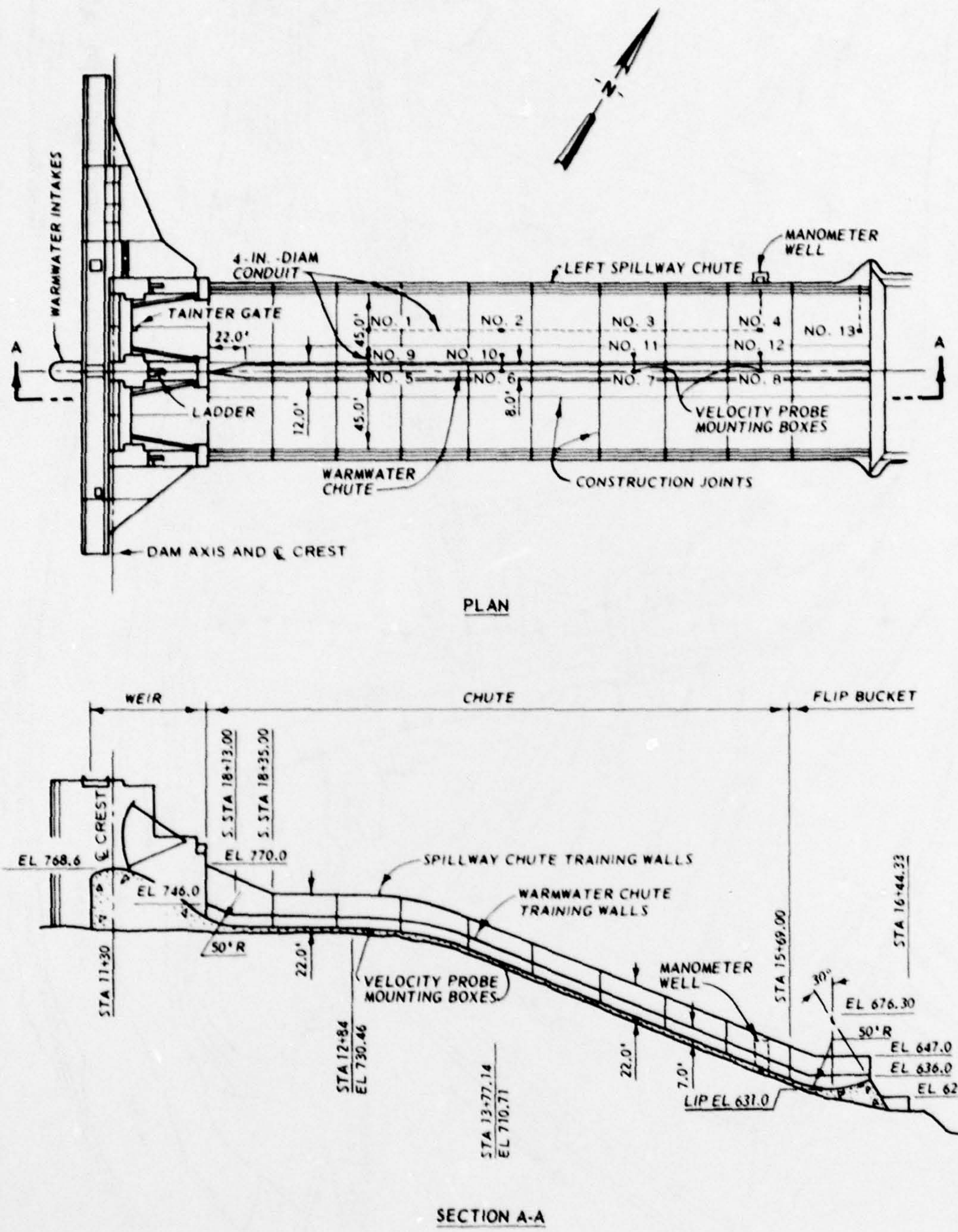
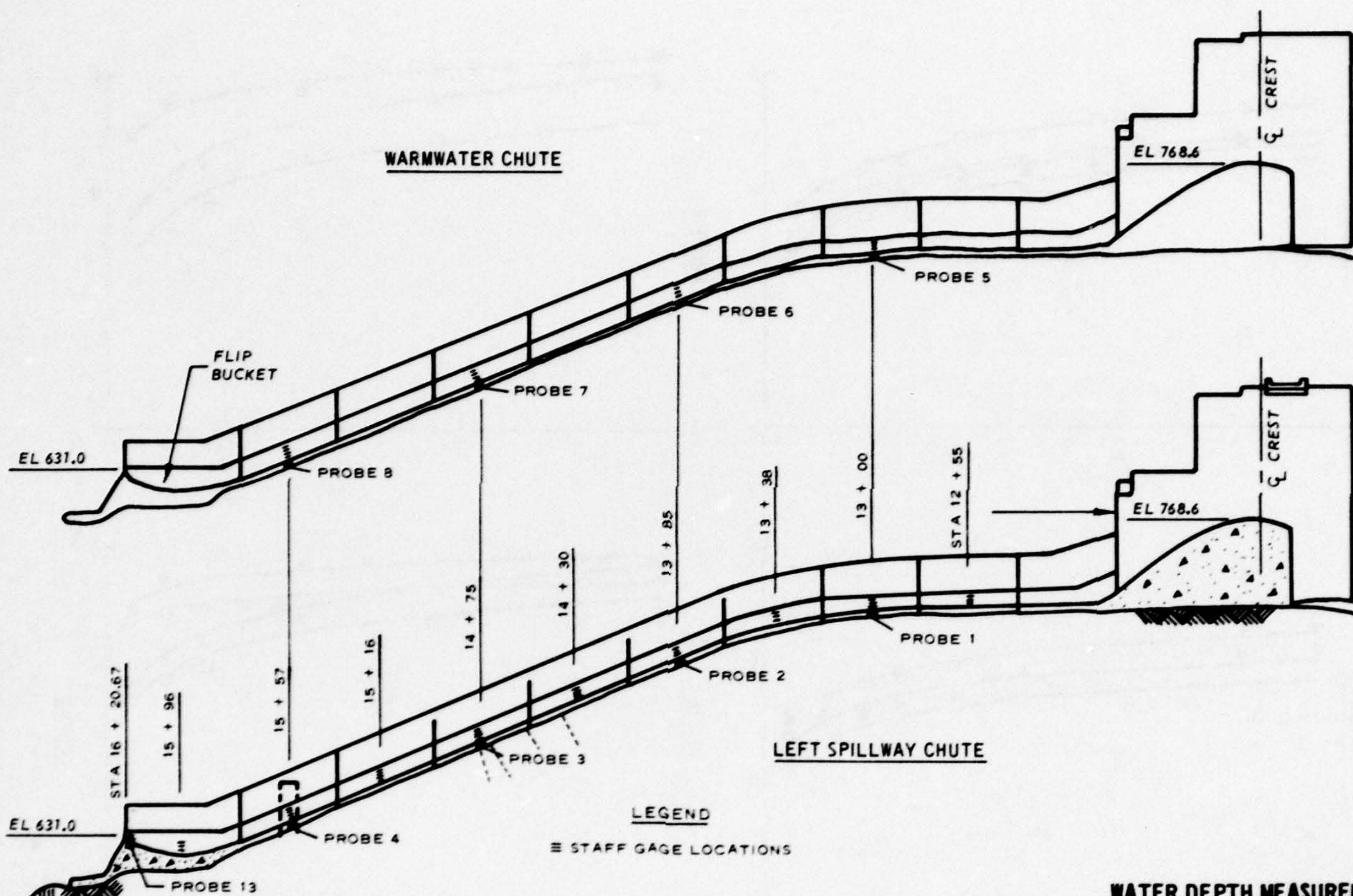

PROJECT PLAN
SCALE IN FEET
TEMPORARY D/S COFFERDAM CREST EL 618.0
D/S PORTAL
DIVERSION TUNNEL
UNGATED SPILLWAY
TOWER ACCESS ROAD
BERM EL 806.0
U/S PORTAL
AVAILABLE QUARRY AREA
(RAYSTOWN BRANCH)
STRIP & OVERWASH MATERIAL
CONTROLLED SPILLWAY
EL 828.0
RIVER
JUNIATA
℄ SPILLWAY
TEST AREA
OPERATORS BLDGS
PARKING
BLDGS
EL 805.0
TOWNSHIP ROAD
BERM EL 785.0
EMBANKMENT DAM
U/S COFFERDAM CREST EL 670.0
FLOW

PLATE 1



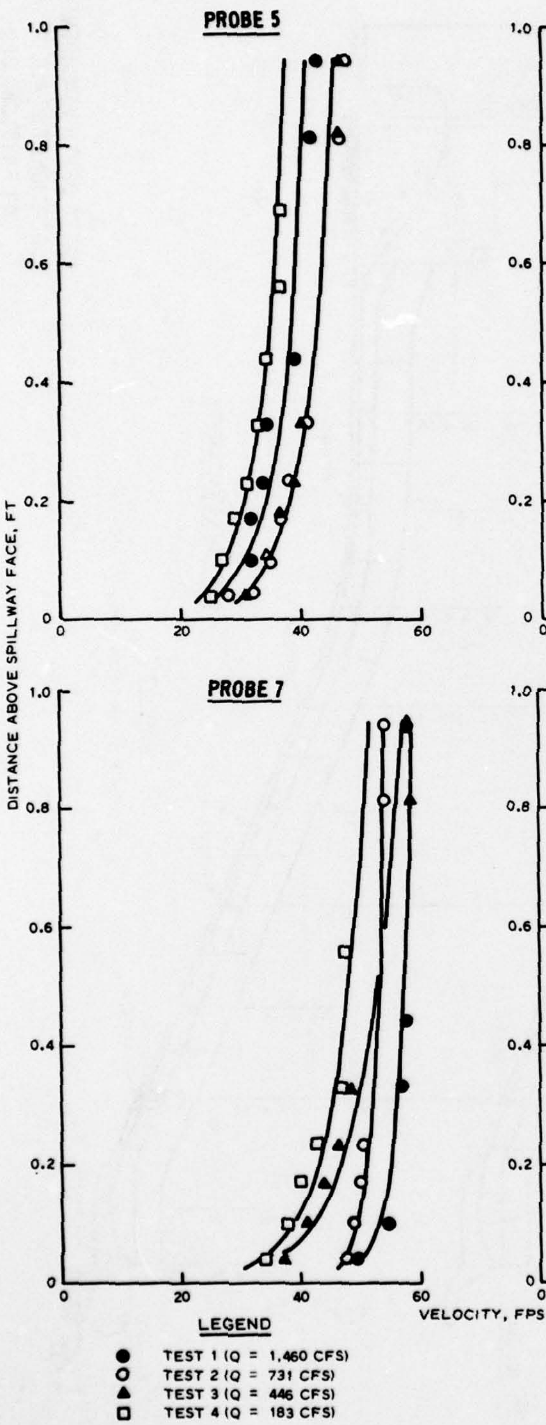
SPILLWAY WEIR, CHUTE,
AND FLIP BUCKET

PLATE 2



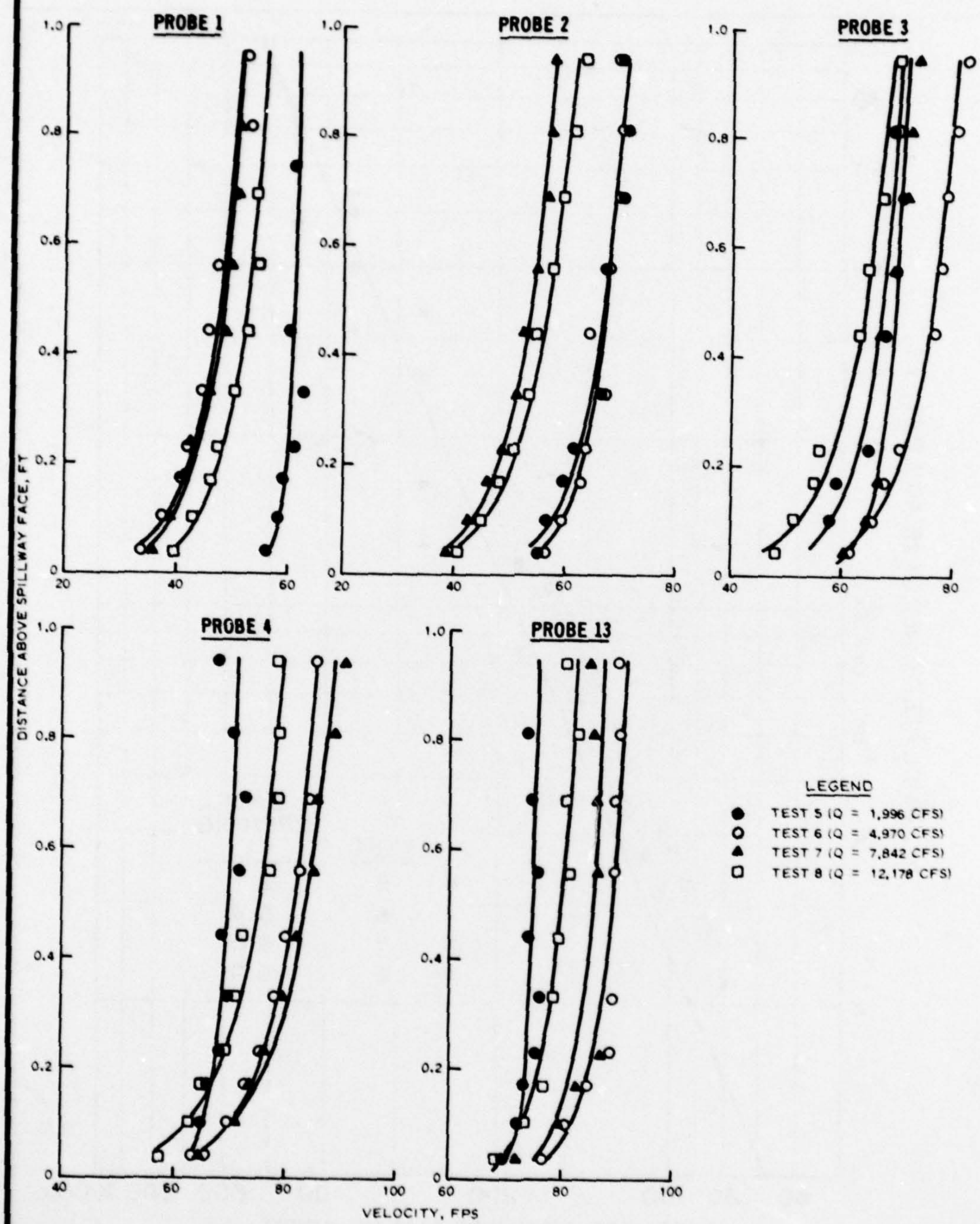
WATER DEPTH MEASUREMENT LOCATIONS FOR ALL TESTS AT RAYSTOWN DAM

PLATE 3

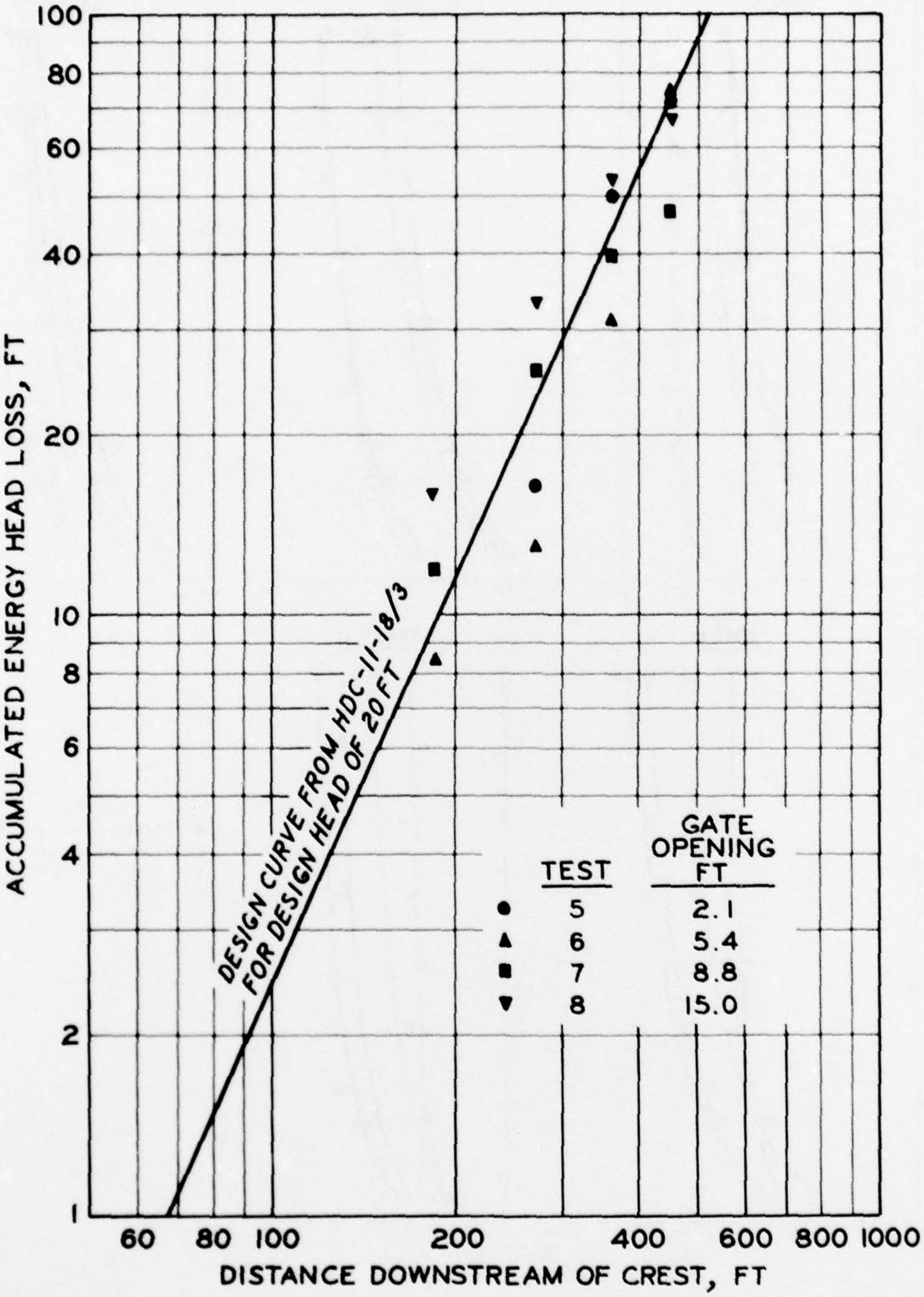


VELOCITY PROFILES
WARMWATER CHUTE TESTS

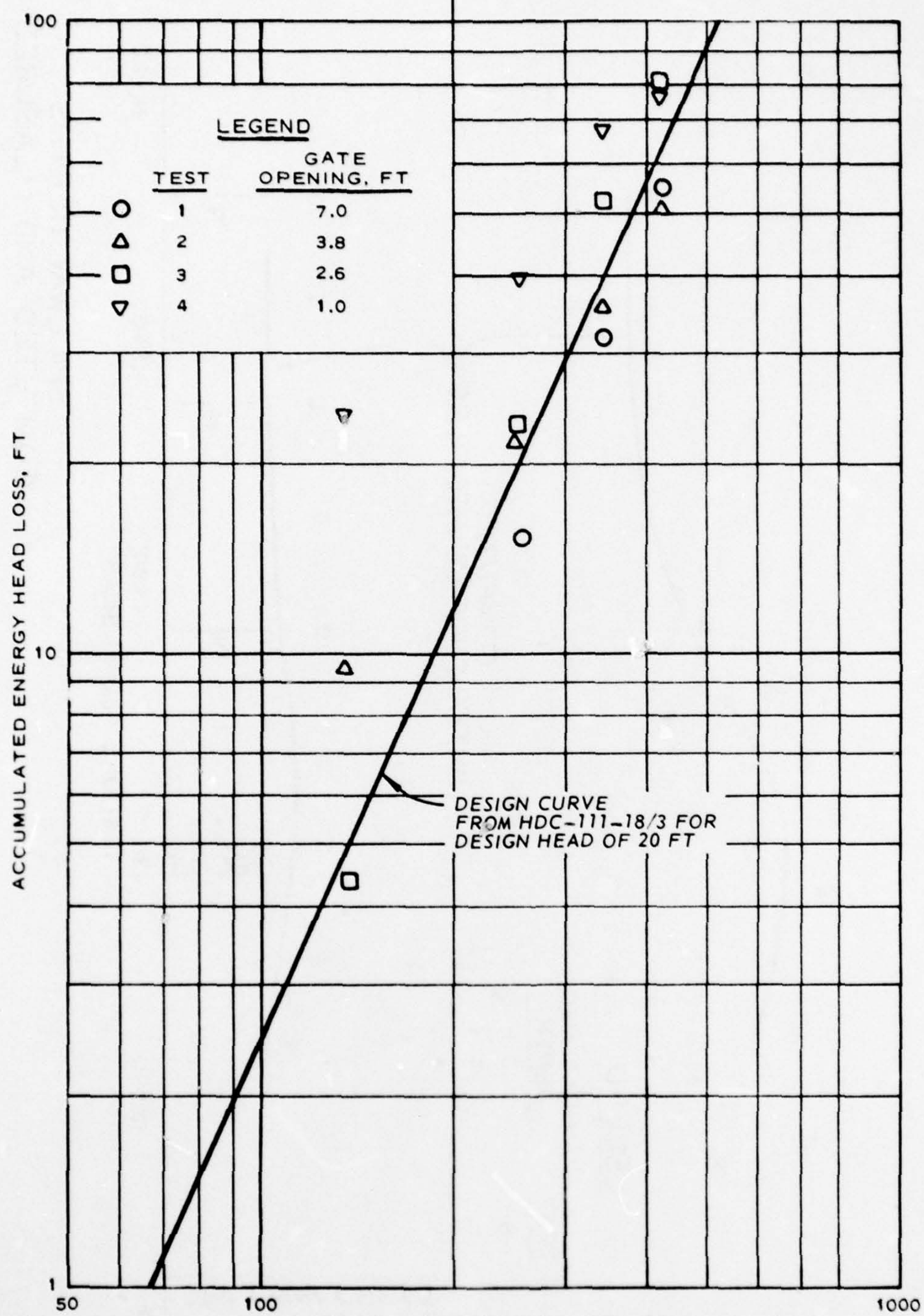
PLATE 4



VELOCITY PROFILES
LEFT SPILLWAY CHUTE TESTS

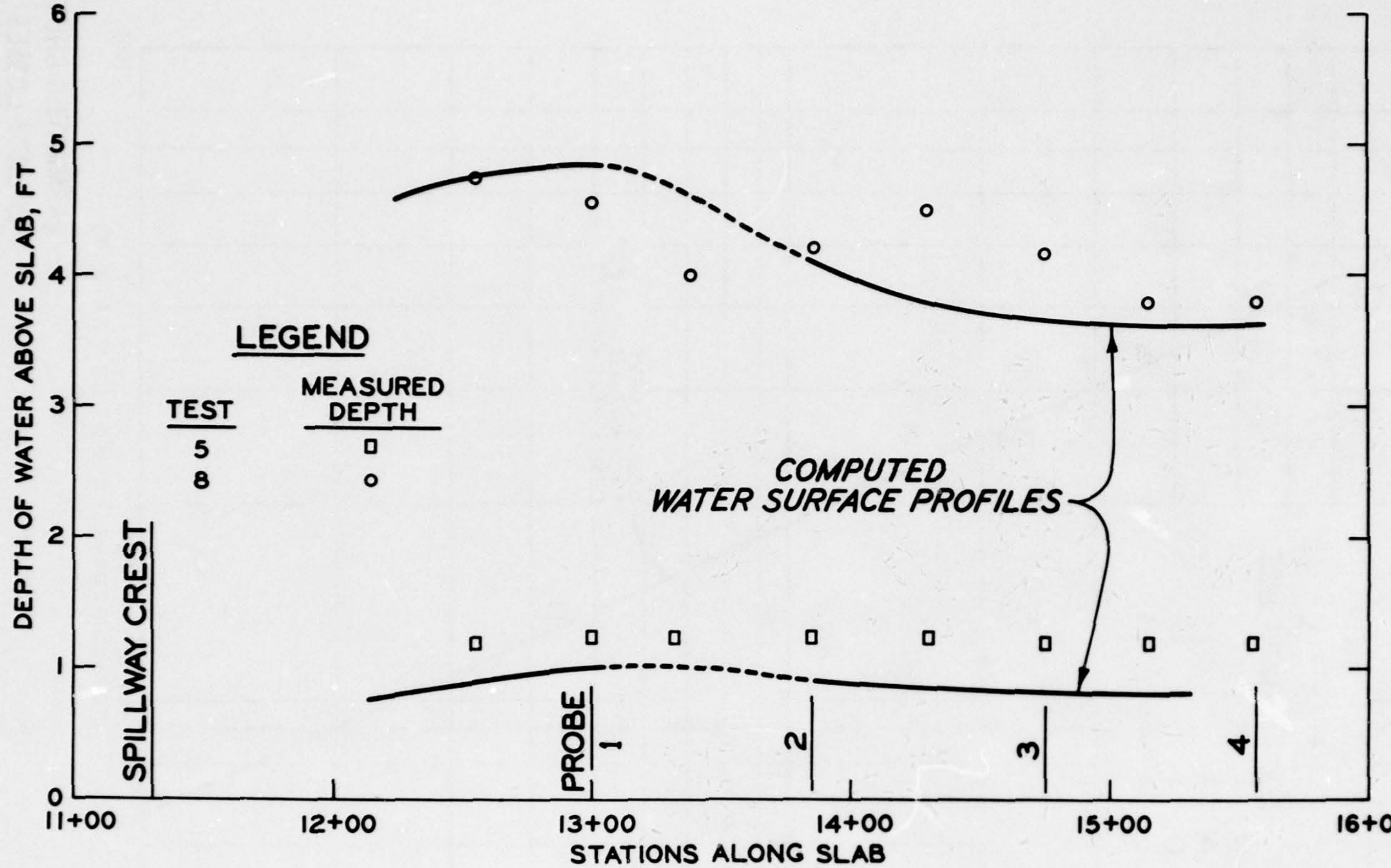


LEFT SPILLWAY CHUTE
ENERGY LOSSES
TESTS 5-8

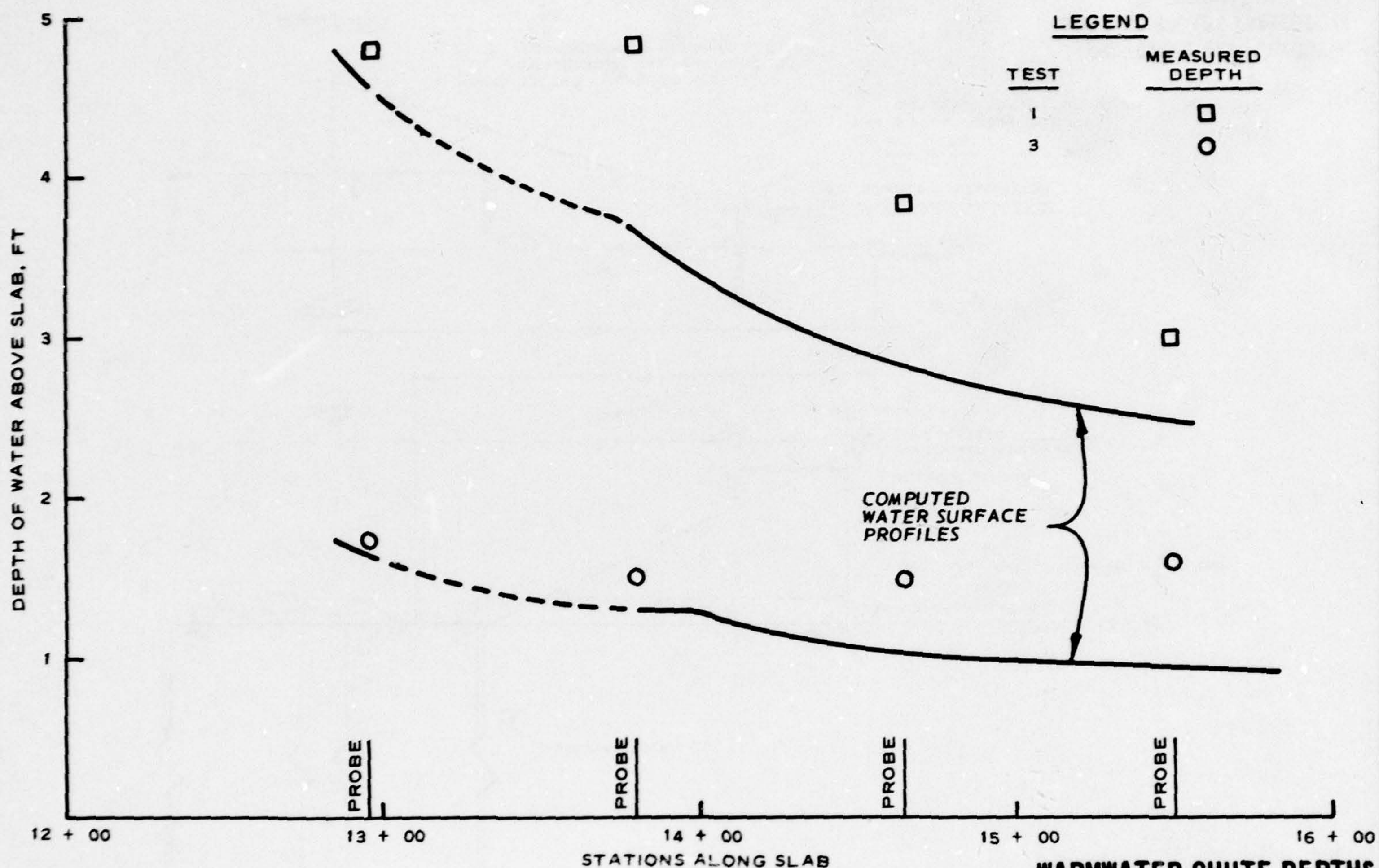


WARMWATER CHUTE ENERGY LOSSES

TESTS 1-4

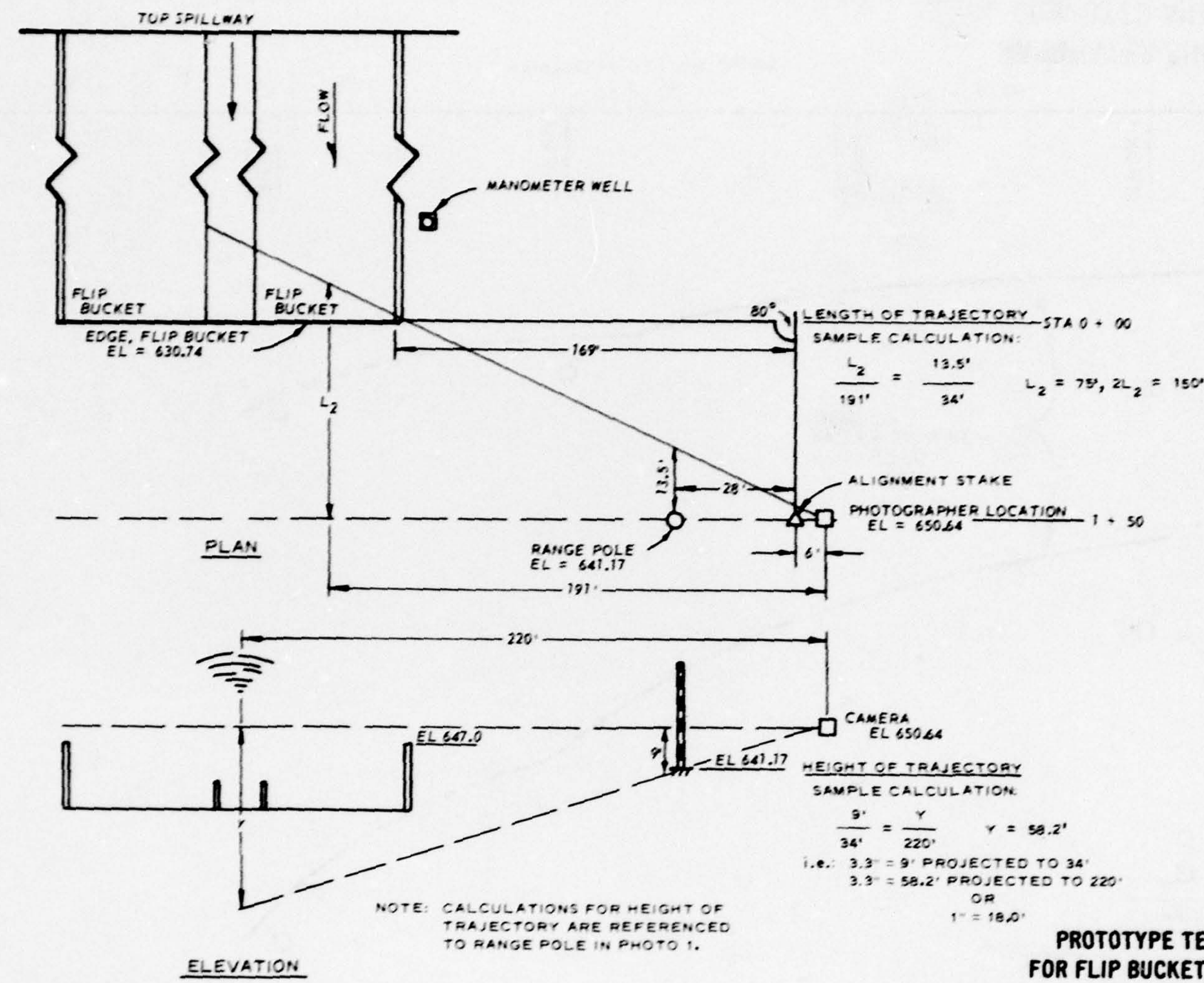


SPILLWAY DEPTHS
COMPUTED AND MEASURED

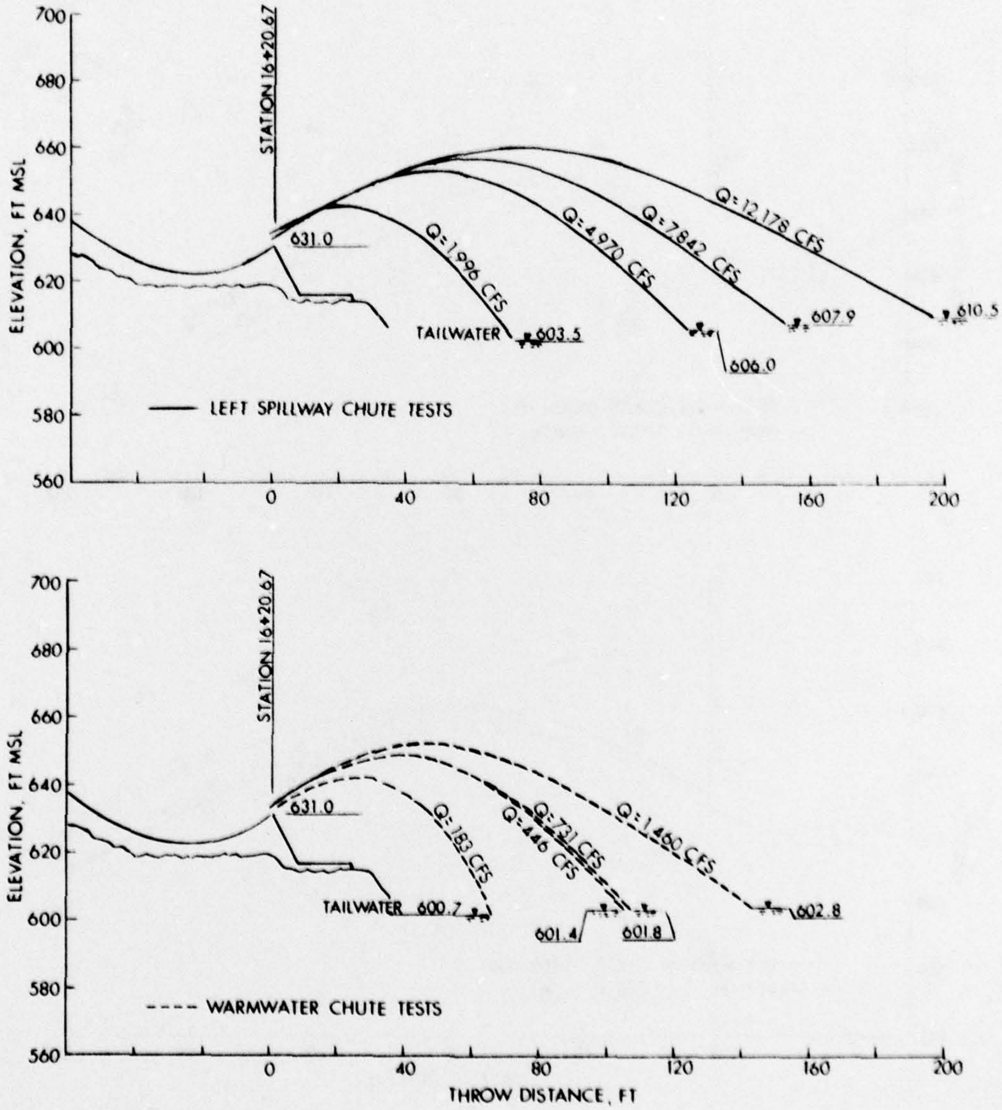


WARMWATER CHUTE DEPTHS COMPUTED AND MEASURED

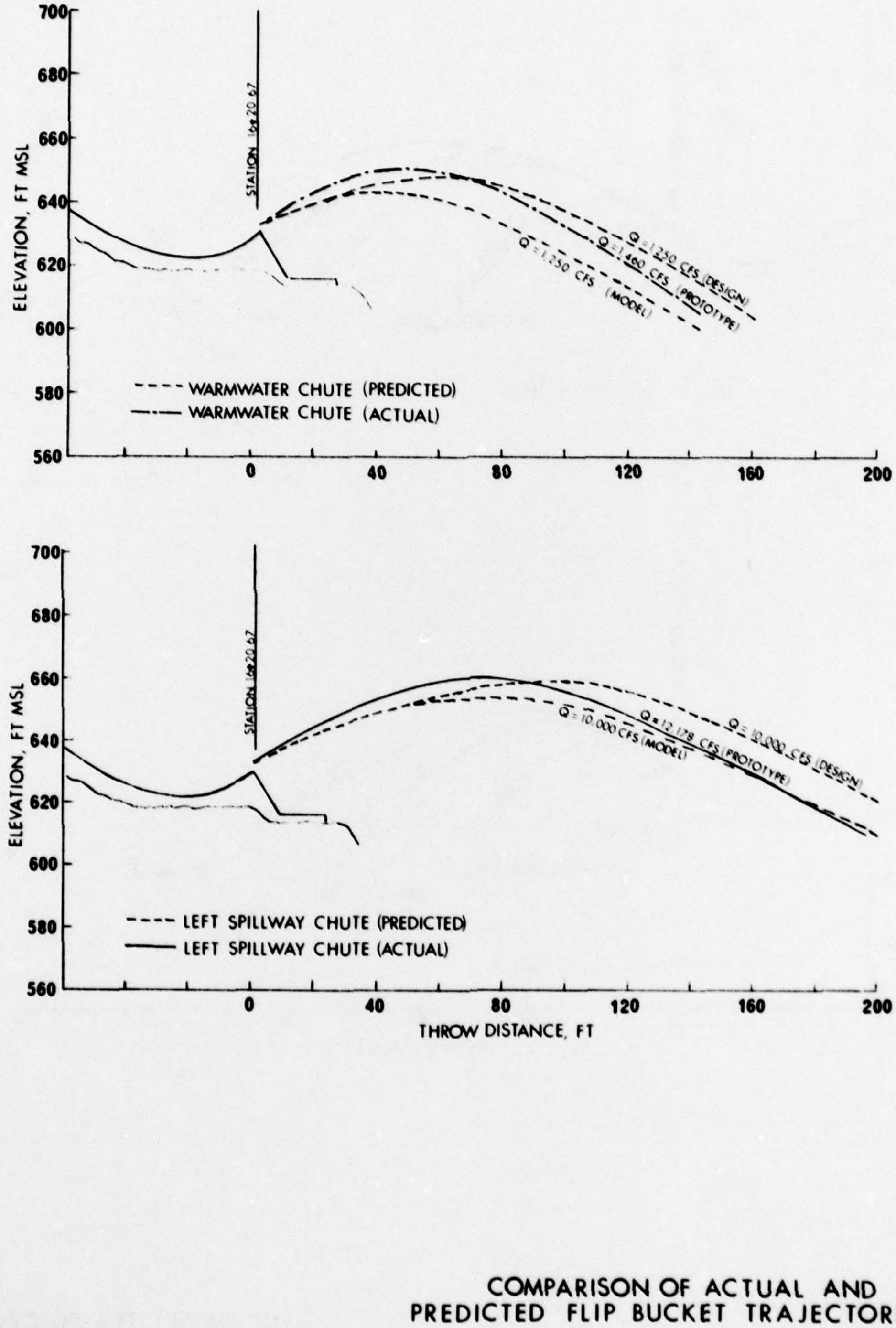
PLATE 10



PROTOTYPE TEST LAYOUT FOR FLIP BUCKET TRAJECTORY DETERMINATION



FLIP BUCKET TRAJECTORIES



COMPARISON OF ACTUAL AND PREDICTED FLIP BUCKET TRAJECTORIES

APPENDIX A: NOTATION

a	Dimensional constant
A	Dimensionless constant
b	Dimensional constant
B	Dimensionless constant
c'_f	Local skin friction coefficient
d	Depth of flow, ft
g	Acceleration, ft/sec^2
H	Elevation of upstream water surface, ft
K_s	Equivalent sand grain roughness
K_s/D	Relative sand grain roughness
q	Unit discharge, cu ft/sec/ft of chute width
Q	Test discharge, cu ft/sec
U	Local velocity, ft/sec
$U*$	Shear velocity, ft/sec
U_∞	Free stream velocity, ft/sec
x	Distance downstream from leading edge of the plate
y	Vertical distance from the chute floor; distance from wall
Z	Elevation of local water surface, ft
δ	Theoretical boundary layer thickness
ρ	Fluid density, slugs/cu ft
τ_o	Boundary shear stress, lb/sq ft

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Fagerburg, Timothy L
Spillway velocity measurement and flip bucket trajectory, Raystown Dam, Juniata River, Pennsylvania / by Timothy L. Fagerburg. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
24, [5] 1 p., 12 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; HL-79-3)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., and U. S. Army Engineer District, Baltimore, Baltimore, Md.
References: p. 24.

1. Chutes. 2. Flow characteristics. 3. Raystown Dam. 4. Spillways. 5. Velocity distribution. 6. Velocity measurement. I. United States. Army. Corps of Engineers. II. United States. Army. Corps of Engineers. Baltimore District. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; HL-79-3.
TA7.W34m no.HL-79-3